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Entrained Flow Reactor Study of KCl Capture by Solid Additives

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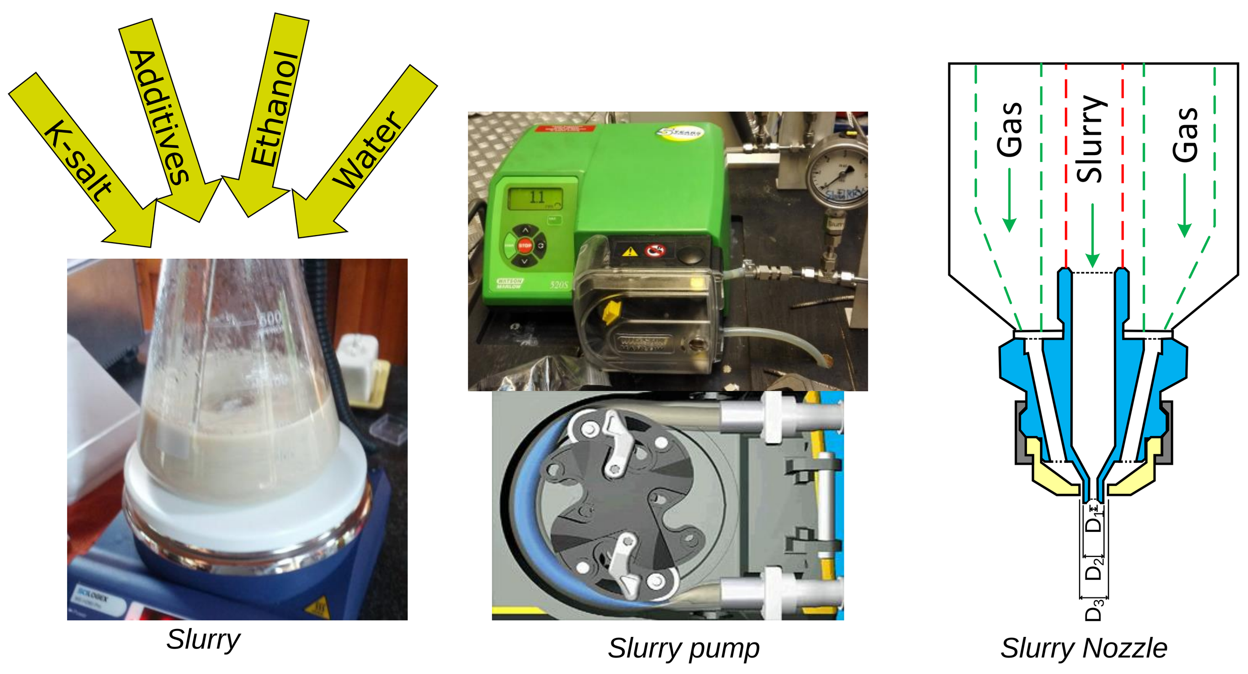
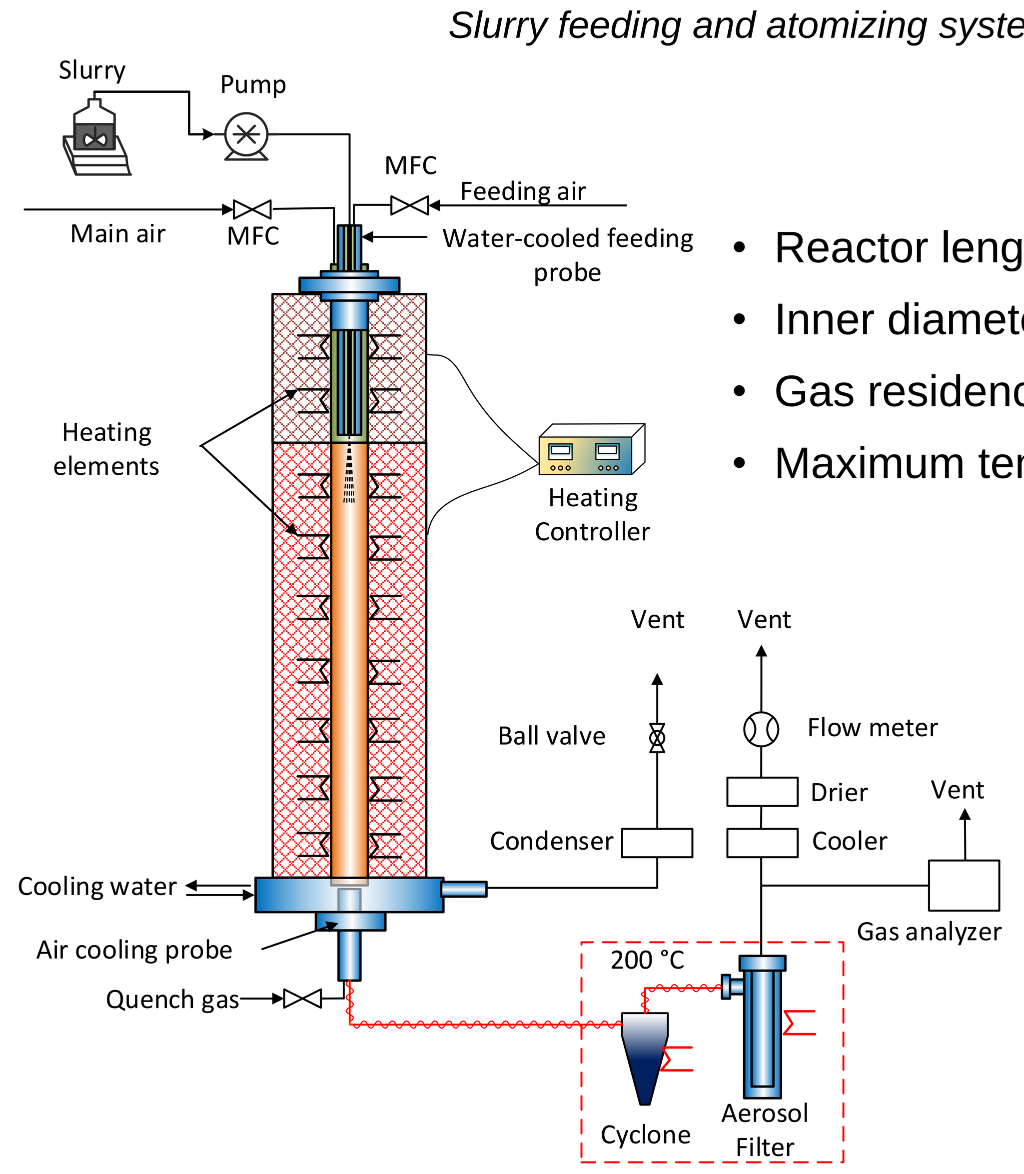
Introduction – An option for abating deposition and corrosion caused by alkali species during biomass combustion, is the introduction of additives into boilers for transforming harmful gaseous alkali compounds (e.g. KCl, KOH) into less corrosive ash species with a higher melting point. Kaolin and coal fly ash have been proved to be very promising additives and have received extensive studies during the past decades. However, most previous studies were carried out in fixed-bed reactors where the reaction conditions are obviously different from that in suspension fired boilers. Detailed knowledge on the reaction between K-species and solid additives under suspension-fired conditions is still limited. In this study, a water slurry containing K-salt and solid additives was introduced into an entrained flow reactor (EFR) to study K-capture at suspension-fired conditions. A model will be developed based on experimental data and recommendations for optimal use of additives in full scale boilers will be provided.

Experimental setup



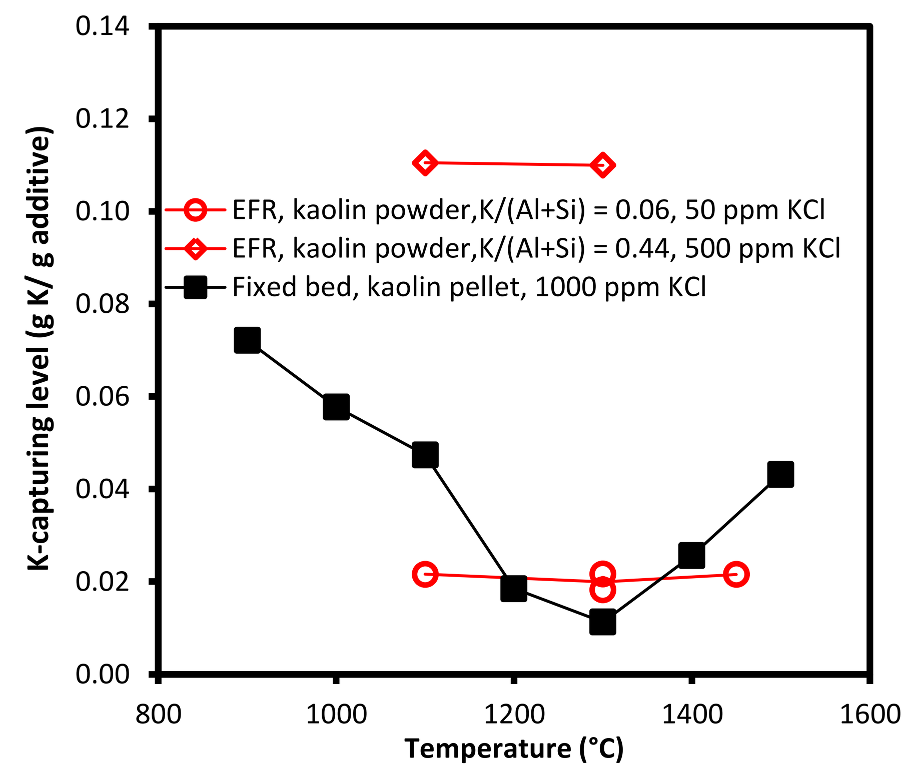
Slurry feeding and atomizing system



- Reactor length : 2 m
- Inner diameter: 79 mm
- Gas residence time : 0.8-0.9 s
- Maximum temp.: 1450 °C

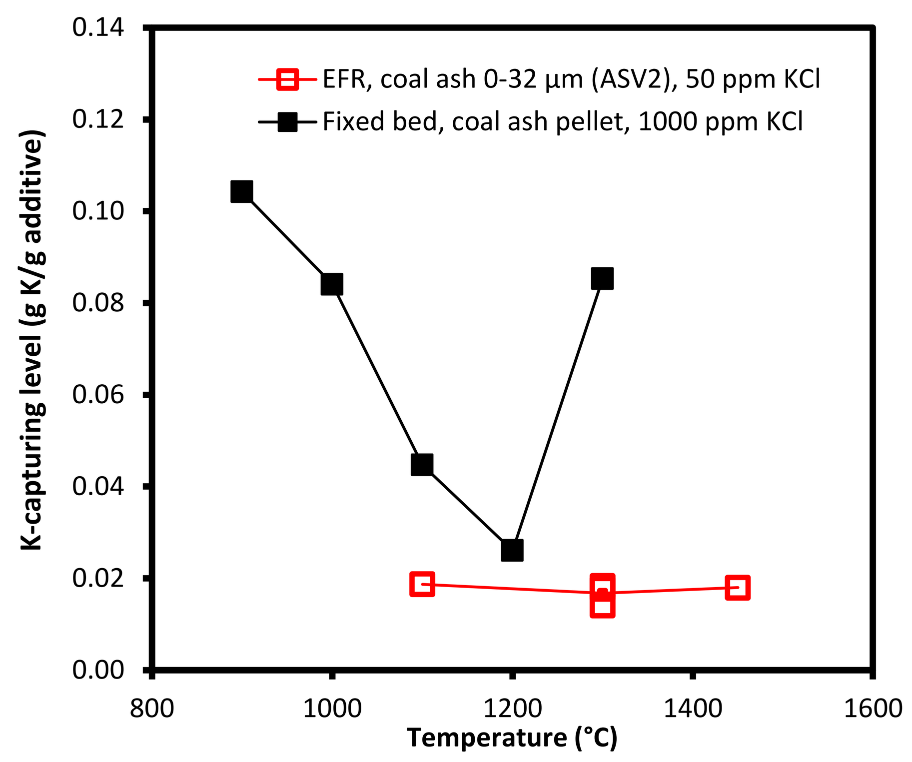
Entrained Flow Reactor (EFR)

Impact of temperature



K-capturing level of kaolin as a function of temperature

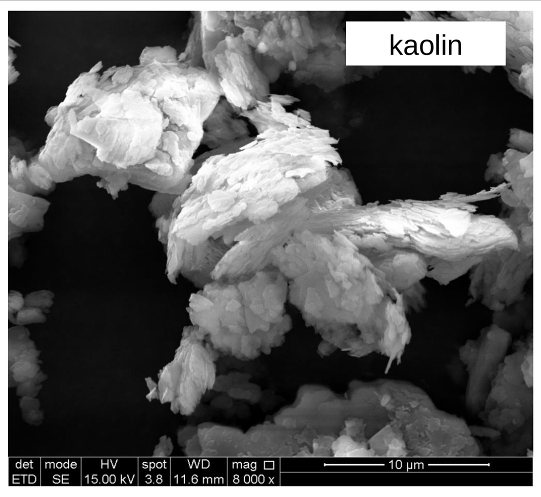
	Entrained Flow Reactor	Fixed Bed Reactor
Particle Size	D_{50} = 5.47 µm	pellet diameter = 1.56 mm
Residence Time	< 1 s	1 h
KCl in flue gas	50 ppm, 500 ppm	1000 ppm
Theoretical maximum C_K is 0.30 g /g kaolin		



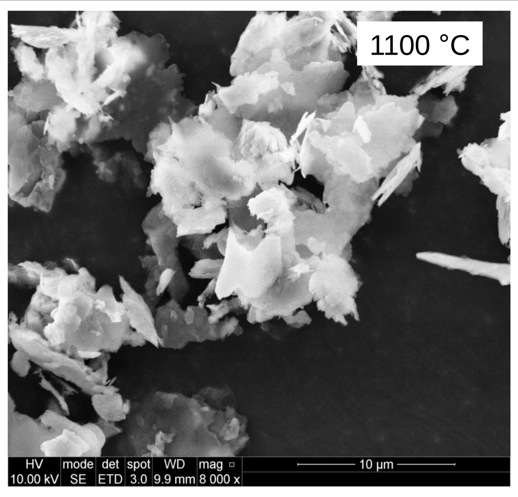
K-capturing level of coal ash as a function of temperature

	Entrained Flow Reactor	Fixed Bed Reactor
Particle Size	< 32 µm	pellet diameter = 1.50 mm
Residence Time	< 1 s	1 h
KCl in flue gas	50 ppm	1000 ppm

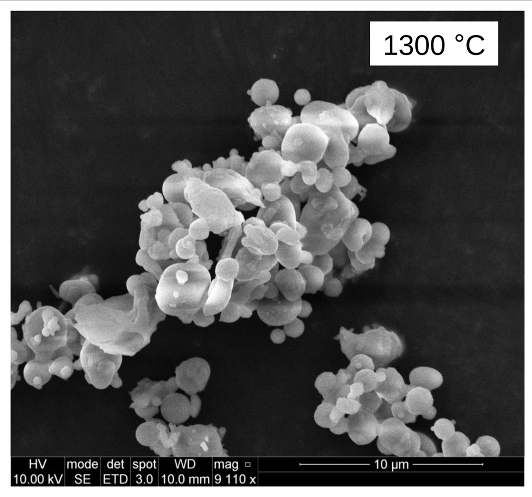
- K-capturing level of kaolin and coal ash does not change with increasing temperature (1100 - 1450 °C);
- The controlling mechanism of K-capturing at suspension-fired conditions is different from that in fixed-bed reactor.



raw kaolin powder, D_{50} = 5.47 µm



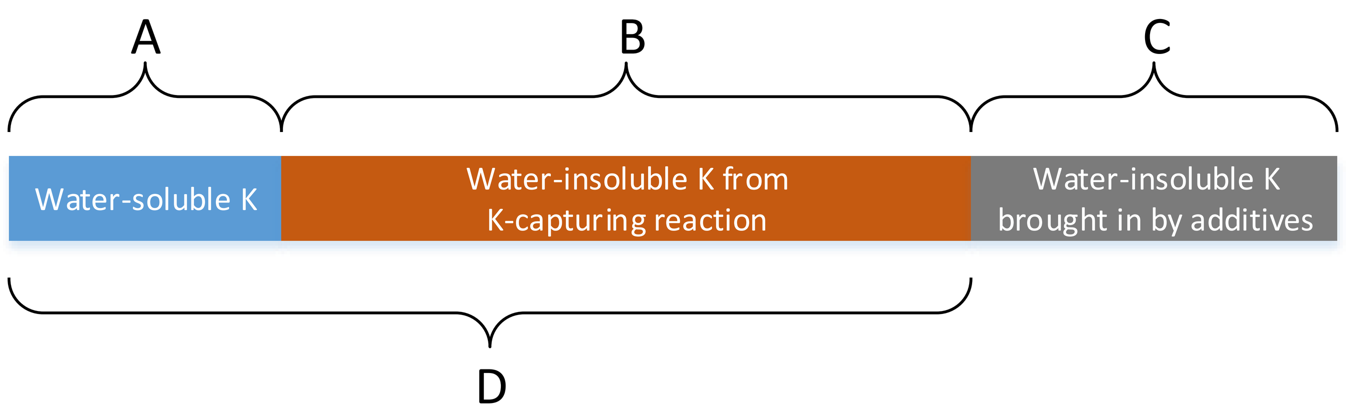
reacted kaolin , 1100 °C, 500 ppm KCl



reacted kaolin, 1300 °C, 500 ppm KCl

- Melting point of reacted kaolin particles is between 1100 °C and 1300 °C;
- Difference of morphology does not affect K-capturing level.

K-capture quantification

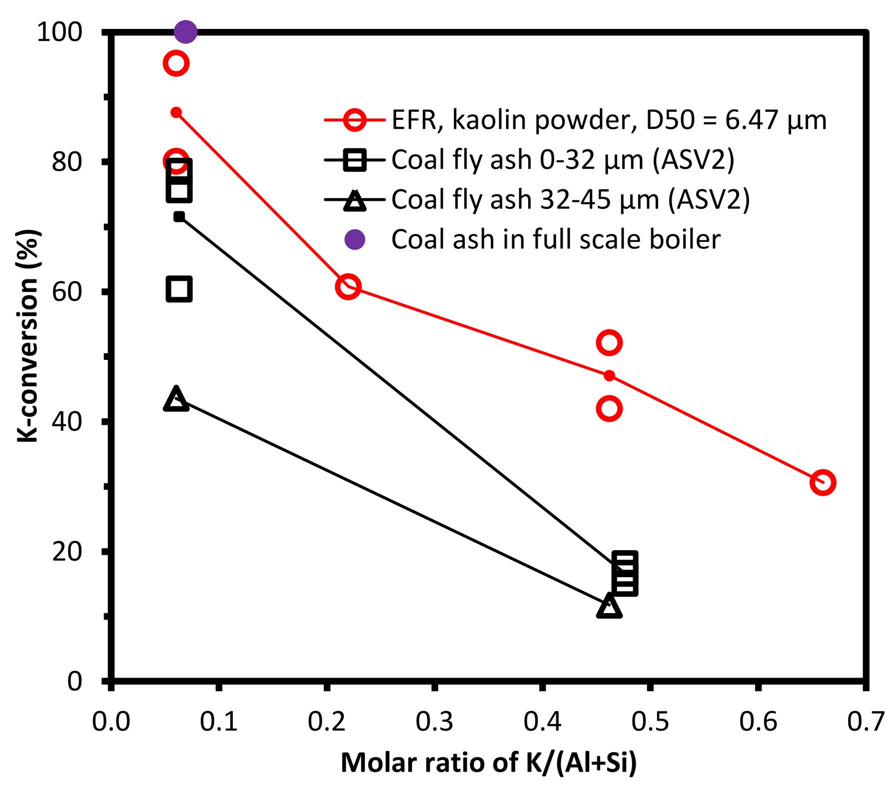


- **K-conversion fraction X_K (%):** the fraction of K transformed into water-insoluble K-species.
- **K-capturing level C_K (g K/g additive):** the mass of K captured by 1 g solid additives.

$$X_K = \frac{B}{D} \times 100\% \qquad C_K = \frac{n_{KCl} M_K X_K}{m_{ad.}}$$

n_{KCl} is the amount of KCl fed into the EFR (mol);
M_K is the molar mass of K (g/mol);
m_{ad} is the mass of additives fed into the EFR (g).

Impact of molar ratio of K/(Al+Si) in reactants



K-capturing level of solid additives as a function of molar ratio of K/(Al+Si) in reactants

- K-conversion decreases with increasing molar ratio of K/(Al+Si) in reactants;
- Kaolin is more effective than coal fly ash for KCl-capturing;
- Finer coal fly ash captures K more effectively;
- K-conversion in full scale boilers is around 100% using coal fly ash, while in EFR it is lower probably due to relatively shorter residence time.

	Entrained Flow Reactor	Full-scale Boiler
Residence time	< 1 s	3-5 s
Additive	Kaolin, coal fly ash	Coal fly ash
K-conversion	52% - 95%	~100 %

Conclusions

- A method for studying additive behaviors in a entrained flow reactor has been developed;
- KCl was effectively converted into water-insoluble K-aluminosilicate by kaolin and coal ash;
- K-conversion increased when molar ratio of K/(Al+Si) in reactant decreased;
- K-capturing level does not change obviously with increasing temperature (1100 - 1450 °C), which is different from that in fixed-bed reactor, indicating different controlling mechanism;

Ongoing and future work

- EFR experiments with different alkali species, like KOH, K_2CO_3 and K_2SO_4;
- Experiments with different coal fly ash to investigate the influence of ash properties;
- Experiments with mullite, quartz, metakaolin to study the kinetics of K-capture;
- Developing a model based on experimental data for optimal utilization of solid additives in full-scale boilers;

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